Non-Linear Controller for Electric Vehicle based on Indian Road Conditions

Poorani Shivkumar
Principal,Hosur Institute of Technology and Science,
Errandapalli Village,Beerpalli (P.O),Ramapuram (via),
Krishnagiri – 635 115
drpooranieee@gmail.com,principal@hits.edu.in

***Abstract*— A nonlinear controller namely sliding mode controller has been designed for the modeled transfer function of DC shunt motor based Electric Vehicle Drive, which takes into account Vehicle parameters, Motor Parameters and Indian Road conditions. The performance analysis of PI controller as well as sliding mode controller based on trending law for the developed transfer function has been analyzed and quantified that sliding mode controller is better and robust for Electric vehicle suitable for Indian road conditions.**

***Index Terms*—Sliding Mode Controller Based on Trending Law, PI controller, Transfer function of Electric vehicle, Concrete, Medium Hard, sand, Indian road conditions.**

I. Introduction

The search for vehicles with improved fuel economy, reduced emissions, and affordable cost without sacrificing the performance, safety, reliability and other attributes of a conventional vehicle has made the Electric Vehicle Technology (EVT) [2, 3, 6,13] as one of the challenges for the automotive industry. The Electric Vehicle is an integration of vehicle body, electric propulsion, energy storage battery and energy management system. The storage battery voltage depends on the charge and load current. Hence the motor should be capable of handling the fluctuations in supply voltage in order to drive the vehicle efficiently. Due to non-linear and time invariant nature of dc motor drives, it is difficult to meet above objectives under different operating conditions using the fixed parameters and structure of controllers. Such conditions improve if adaptive controller is employed in the vehicle. Recently one of the adaptive controllers like sliding mode controller has attracted much attention in the field of automobile engineering. A current control method based on sliding mode control design has been done for Induction motor drive [1]. The proposed control design uses two sliding mode controllers to regulate the *d*-axis and *q*-axis stator currents respectively. The design of the controllers includes two steps here. Sliding mode control based on trending law is the recent technique nowadays which is introduced here in this paper. More over the sliding mode controller (SMC)[12] approach is a best method to design a controller with desired non-linear dependence between the input and output of the controller and also to control the speed of separately excited DC shunt motor. The parameters of the SMC system are chosen properly to form the desired adaptive controller. The focus of this research is to incorporate SMC based on trending law, for the developed transfer function of the electric vehicle that includes vehicle dynamics, road dynamics and motor parameters. The paper is organized as follows: Section 2 provides the Modeling of transfer function for Electric Vehicle based on Indian road conditions namely Concrete, Medium Hard and Sand. Section 3 describes the PI controller design and its performance of the various Indian road conditions. Section 4, the design of SMC based on trending law for Indian road conditions and its characteristics .Section 5 conclusions are drawn and finally the references.

II. Modeling of Transfer function of Electric Vehicle power train

The transfer function of the linear system is defined as the ratio of the Laplace transform of output variable to the Laplace transform of the input variable, with all the initial conditions assumed to be zero. The transfer function of a system or element represents the relationship describing the dynamics of the system under consideration. The electric vehicle transfer function is developed based on motor parameters, rolling resistance and the vehicle parameters [10].The motor used is of DC shunt type motor [7]. It is armature controlled dc motor. It is a rear wheel drive. The dc motors are generally used in the linear range of the magnetization curve. The transfer function changes as the rolling resistance values change for the various terrain. The speed is determined where the below stated parameters has been taken here

Iv = Vehicle Inertia (kg-m2)
fr= Rolling resistance
J = moment of inertia of motor (kg-m2)
fo= Viscous friction coefficient of motor (Newton-m/rad/sec)
KT=torque developed by motor (Newton-m)
Kb = back emf constant
Ra/La is Negligible are taken into account in this transfer function. The transfer function of the various terrains has been derived. The concrete transfer function is shown here. Similarly other terrain transfer function has been derived [10].

For the concrete

$$G(s) = \frac{0.913242}{1.39s^2 + 1.215s + 0.913242} \tag{1}$$

For the medium hard

DOI: 01.IJEPE.4.1.1075

ACEEE Int. J. on Electrical and Power Engineering, Vol. 4, No. 1, Feb 2013

$$G(s) = \frac{0.913242}{1.39s^2 + 1.28s + 0.913242} \qquad (2)$$

For the sand

$$G(s) = \frac{0.913242}{1.39s^2 + 1.5s + 0.913242} \qquad (3)$$

III. Controller Design

A. Selection of PI controller and its performance

A controller produces an output signal consisting of two terms, one proportional to the actuating signal and the other proportional to its integral. Such controller is called proportional plus integral controller (PI) [4,5,8,7]. The transfer function has been developed for the various road conditions like Concrete, Medium Hard and Sand. The response of the transfer function changes with the road dynamics .The designed transfer function for the various terrains has been tuned using the PI controller. The closed loop system response is found to meet the designed specifications. Figure 1 shows the general block diagram of the transfer function with the PI and Sliding Mode controller. The proportional integral controller is tuned using Ziegler Nichols method [4,5,8,7] and the gain is also adjusted such that the performance of the response is improved. The transfer function is a varying one, as fr varies the whole transfer function also varies. The response is taken for each Indian terrain as Concrete, medium hard and sand. The fr rolling resistance for various terrain is Concrete=0.015, medium hard = 0.08, sand =0.30 [11]. Then the transfer function for the smooth, sand and medium hard is tuned using the PI controller as shown in Figure 2. While doing each simulation for each terrain type namely concrete, medium hard and sand the transfer function for each terrain will also change simultaneously. The PI controller has to be tuned each time for each terrain. The responses for the concrete terrain is shown in the Figure 3,The response for the Medium Hard terrain is shown in figure 4 and finally the response for the sand terrain is shown in Figure 5. From the response it is clear that for smooth terrain it could cover a long distance, and the maximum overshoot is very less as compared to other terrain. In medium hard terrain the response is similar to those of concrete.

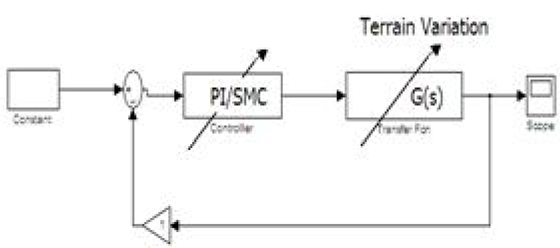

Figure 1: General Block diagram of the Transfer function with controllers

Whereas for sand terrains the maximum overshoot is very less and rises time is very less. This is because with increase in rolling resistance the vehicle speed reduces, which is clearly inferred from the sand terrain response. The scaling factor has a crucial influence on the performance and stability of the system. It improves and acts as a gain in the classical PI controller [9,14]. Due to non-linear and time variant nature of motor drives, it is difficult to meet these objectives under different operating conditions using the fixed parameters and structure of controllers. Then adaptive controllers have to be employed .so the sliding mode controller based on trending law has been employed to overcome these difficulties and is discussed in the next section.

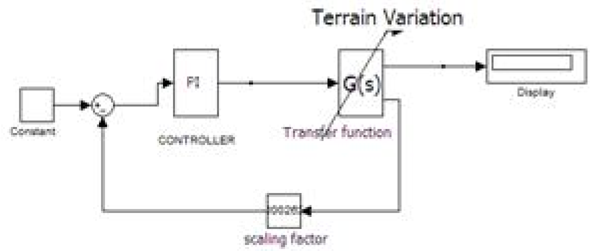

Figure 2: Block diagram of PI controller with the transfer function of all terrains

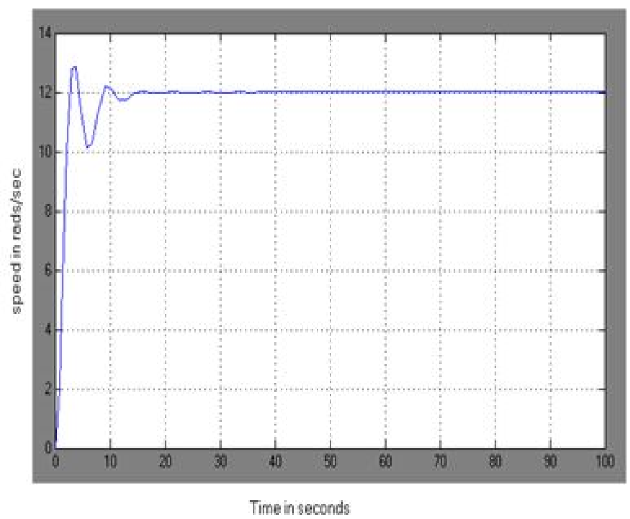

Figure 3: Response of the control loop of PI controller for the concrete terrain

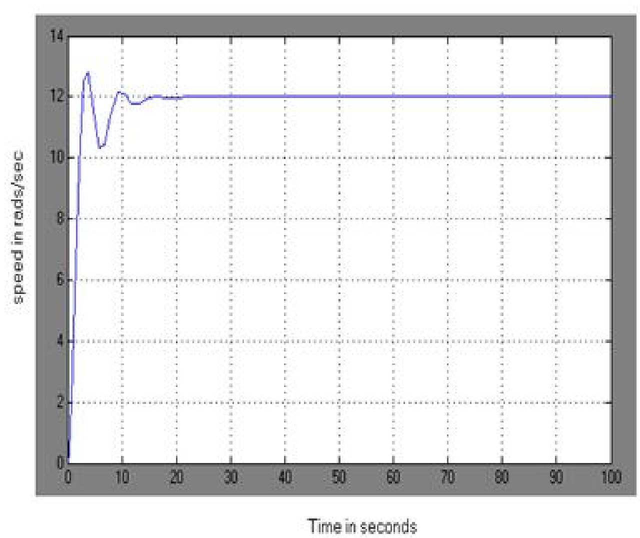

Figure 4: Response of the control loop of PI controller for the Medium Hard terrain

DOI: 01.IJEPE.4.1.1075

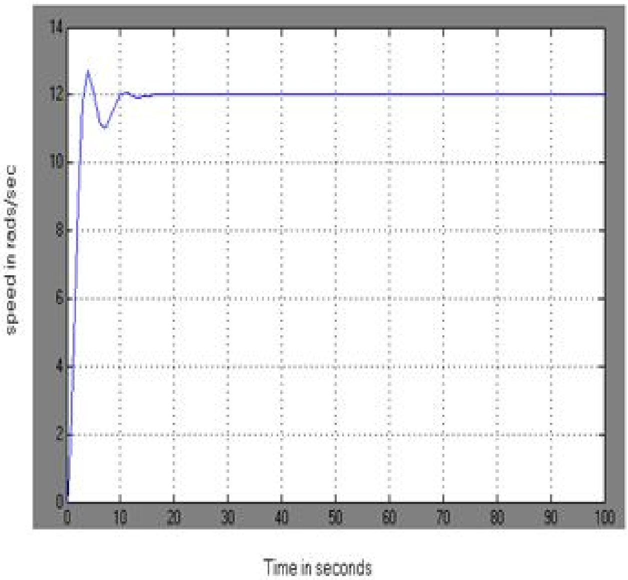

Figure 5: Response of the control loop of PI controller for the Sand terrain

IV. Slide Mode Variable Structure Control

Interest to Sliding Mode Control [12, 18, 19, 20, and 21] is explained by the robustness with respect to plant parameter variations and disturbances. On the other hand sliding motions enable decoupling the overall motion into independent partial components of lower dimensions. Due to these properties the sliding mode control methods are efficient tool to control high order nonlinear dynamic systems operating under uncertainty conditions, which is common for the processes in automotive industry. Variable structure systems (VSS) [17, 19] consist of a set of continuous subsystems with a proper switching logic and, as a result, control actions are discontinuous functions of system state, disturbances and reference inputs. The variable structure system is governed by equations (4) to (6). The above stated function is to meet the following four conditions:(i) Slide mode exists.(ii)Reaching condition, all the state points except on the Switching line could reach the switch line in limited time,(iii) Ensure the stability of sliding motion,(iv)Satisfying the requirements of VSS dynamic quality.

$$\{\frac{dy}{dx} = f(x,u,t), x \in R^n U \in R^m t \in R \quad (4)$$

$$\{y = u(x) \quad y \in R^n \; n \geq m \geq L \quad (5)$$

And switching function is defined by

$$s = s(x) \qquad s \in R^m \quad (6)$$

To solve the control function u_i

$$u_i = \{u^+_i \; s_i(x) > 0 \quad (7)$$

$$u_i = \{u^-_i \; s_i(x) < 0 \quad (8)$$

A. Slide Mode Controller Based on Trending Law

The Invariability of slide mode variable structure [15,16] on the parameters perturbation and disturbances is the cost of the high-frequency chattering of controlled variable. Moreover, the limited accelerated velocity owing to the limited controller's amplitude, system's inertia, switching's hysteresis, state measuring error and large sampling time of computer sampling system all can overlap a saw tooth chattering trajectory on the smooth slide mode. Consequently, how to weaken the chattering is important for designing a slide mode controller for practical applications.

B. Typical Trending Laws

(i) Constant Velocity Trending Law:

$$s^{\cdot} = -\varepsilon\, \mathrm{sgn}(s), \varepsilon > 0 \quad (9)$$

Where constant $\in$ is the velocity of system trending to the switching surface s(x) =0.

(ii) Exponent Trending Law:

$$s^{\cdot} = \varepsilon\, \mathrm{sgn}(s) - ks \quad \varepsilon > 0, k > 0 \quad (10)$$

When s > 0, s = - ε- ks is exponent trending item, and its root is s = s (0) e^{-kt}, i.e. the velocity of trending to the switching surface gets slower.

C. Slide Mode Controller Based on Exponent Trending Law

The Exponent Trending Law equation is chosen to design the sliding mode controller for Electric Vehicle system. In the exponent trending process, trending velocity changes from a bigger value to zero, which can make trending time shorter. And the velocity arriving at the switching surface is smaller. For the simple Exponent Trending, the Trending is a progressive process, and couldn't let the moving point arrive at the switching surface in limited time. Hence, the switching surface doesn't turn up slide mode. So addition of a constant velocity $s^{\cdot} = -\varepsilon$ sgn(s) to make the trending velocity not to be zero while s is approach to zero, which could ensure that the system can arrive at stable point in limited time.
According to sliding mode equation,

$$s(x) = C_1 x_1 + x_2 \quad (11)$$

$$s^{\cdot} = c x_1^{\cdot} + x_2^{\cdot} \quad (12)$$

Submitting the system parameters into Equation (10), the output of slide mode controller is obtained:

$$U_d = \frac{1}{135}\left[(c-112)x_2 + \xi\, \mathrm{sgn}(\alpha_1 - \alpha_2) + k(\alpha_1 \alpha_2)\right] \quad (13)$$

D.Performance of Sliding Mode Controller for the Electric vehicle Transfer function

In this section the transfer function for various Indian road conditions like Concrete, Medium hard and sand has been taken into account .The Sliding Mode controller based on Trending law has been taken into account for analyzing the performance of the various Indian road conditions .Figure

DOI: 01.IJEPE.4.1.1075

6 shows the simulink model of the SMC with transfer function of Electric vehicle. The responses of the SMC have been shown in Figure 7,8and 9 for the Terrains like Concrete, Medium Hard and Sand respectively. The Table I show the performance criteria’s of PI and SMC controller and it has been inferred that Sliding mode controller is found to be better and robust controller for the Electric Vehicle.

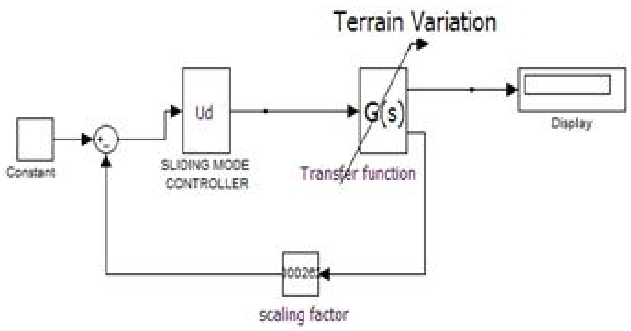

Figure 6: Block diagram of SM controller with the transfer function of all terrains

Conclusions

This research has been to quantify that the sliding mode controller based on trending law for the designed transfer function for a DC shunt motor with respect to Indian Road conditions is better than the PI Controller. The various characteristics like rise time, peak time, settling time, delay time, Maximum peak overshoot, delay time and steady state error has been analyzed using both the conventional controller PI and non linear controller namely sliding mode controller for the various terrains of Indian road conditions. The numerical results from the Table 1 confirm the validity of the sliding mode controller based transfer function for the electric vehicle and prove that its characteristics is robust than the PI controller. The values mainly steady state error proves that there is no error at all and similarly fast settling time and delay time seems to be very low. More over peak overshoot seems to be a very small value which again quantify that the sliding mode controller proves to be better. In future fuzzy sliding mode controller can be implemented.

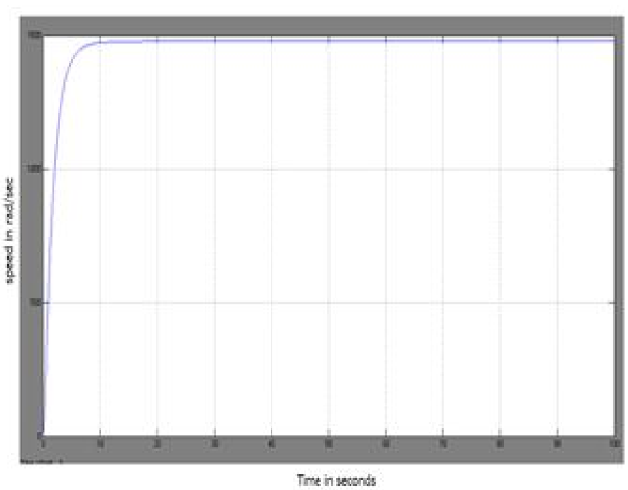

Figure 7: Response of the control loop of sliding mode controller for the concrete terrain

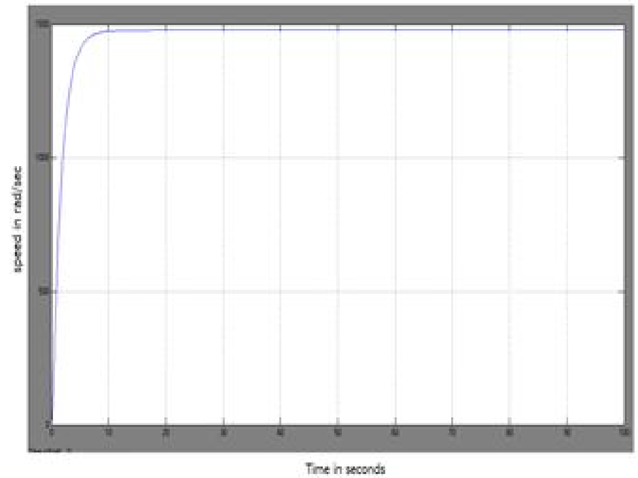

Figure 8: Response of the control loop of sliding mode controller for the Medium Hard terrain

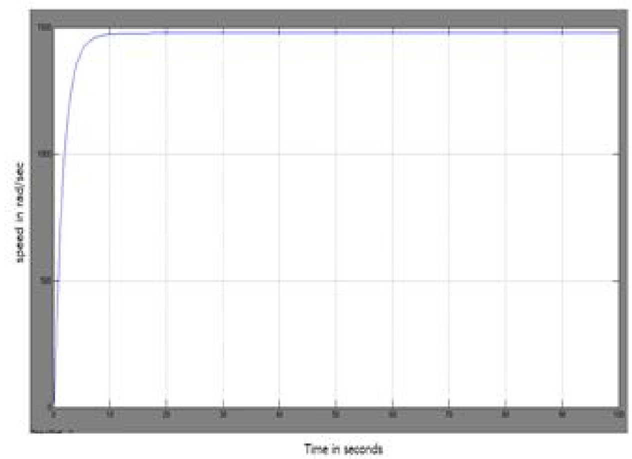

Figure 9: Response of the control loop of sliding mode controller for the Sand terrain

References

[1] Abdelfatah Nasri, Abdeldjebar Hazzab ,Ismail K. Bousserhane, Samir Hadjeri,, Pierre Sicard(2008) ,Two Wheel Speed Robust Sliding Mode Control for Electric Vehicle Drive, SERBIAN JOURNAL OF ELECTRICAL ENGINEERING ,Vol. 5, No. 2, November, 199-216.

[2] Baruch Berman and George H. Gelb (1974), ‘Propulsion Systems for Electric Cars’, IEEE Transactions on Vehicular Technology, Vol.VT-23, No.3, pp.61-72.

[3] Chan C.C. (1993), ‘An overview of electric vehicle Technology’, Proceedings of IEEE, Vol.81, No.9, pp.1202-1213.

[4] George Ellis (2005),”Control System Design Guide”, Academic press ,An imprint of Elsevier, Third Edition

[5] Ho W.K., Hang C.C. and Zhou J.H. (1995), ‘Performance and gain and phase margins of well known PI tuning formulas’, IEEE Transactions on Control Systems Technology, Vol. 3, No.2, pp.245-248.

[6] Iqbal Husain and Mohammad Islam S. (1999), ‘Design, Modeling and simulation of an electric Vehicle Systems’, SAE1999-01-1149, pp. 63-73.

[7] John Chiasson and Bodson M. (1993), ‘Non linear control of a DC shunt motor’, IEEE Transactions on Automatic Control,Vol.38, No. 11, pp. 1662-1666.

DOI: 01.IJEPE.4.1.1075

[8] Nandam P.K. and Sen P.C. (1987), 'Analog and Digital speed control of DC Drives using proportional-integral and integral-proportional control techniques',IEEE Transactions on Industrial Electronics,Vol.IE-34, No.2, pp.227-233.

[9] Stefani, Shahian, Savant, Hostetter (2004), "Design of feedback control systems", oxford University press, fourth edition.

[10] Poorani S, UdayaKumar K. and Renganarayanan S. (2007), 'Design of a fuzzy based controller for Electric Vehicles on Indian roads', Proceedings of the Institution of Mechanical Engineers, Part I, Journal of Systems and Control Engineering, 2007,221(1),61-74.

[11] Thomas D.Gillespie (1999), "Fundamentals of Vehicle Dynamics", Society of Automotive Engineers Group

[12] Vadim I. Utkin, (1993) "Sliding Mode Control Design Principles and Applications to Electric Drives", IEEE Transactions on Industrial Electronics, vol. 40, no. 1, February 1993.

[13] Chan C.C Chau K.T (2001),"Modern Electric Vehicle Technology",Oxford University,UK

[14] Richard C.Dorf,Robert H.Bishop,:Modern Control System, Addison Wesley Longman , Inc.1998

[15] J.Xu et al., "Design of Variable Structure controllers with continuous Switching Control," Int, J. Of Contr., vol.65, 1996, pp.409-431

[16]Khalifa Al-Hosani, Vadim Utkin and Andrey Malinin,(2007)"Sliding Mode for Industrial Controllers", the Ohio state University, IKOR, USA.

[17] P.Zlateva, "Variable – Structure control of non-Linear Systems", Contr. Engineering Practice, vol.4, 1996. pp. 1023-1028

[18] Slotine, J-J. (1984), "Sliding Controller Design for Non-Linear Systems". International Journal of Control, 40 (2), p.p 421-434.

[19] Utkin, V.I, "Variable Structure systems with sliding modes", IEEE Transactions on Automatic Control, Vol.AC-22, No.2, pp.212-222, April 1977.

[20] Utkin,V., Guldner, J., & Shi, J. (2009). "Sliding Mode Control in Electro – Mechanical Systems." CRC press, Taylor & Francis Group.

[21] Utkun,V & Shi,J, "Integral Sliding Mode in systems operating under uncertainity conditions," 35th IEEE conf. On Decision and Contr., pp.4591-4596, 1996.

TABLE I.PERFORMANCE CHARACTERISTICS OF CONTROLLERS

S.No	Types of Terrain	Performance Criteria	PI controller	Sliding Mode controller
1.	Concrete	Rise time (t_r)	1	0.0001
		Settling time (t_s)	37	10
		Peak Time (t_p)	5	1
		Max peak Overshoot (M_p)	12.8	2
		Delay Time (t_d)	0.01	0.0001
		Steady State error (e_{ss})	0	0
2.	Medium hard	Rise Time (t_r)	0.8	0.0001
		Settling Time (t_s)	21	10
		Peak Time (t_p)	3	0.1
		Max peak Overshoot (M_p)	12.7	2
		Delay Time (t_d)	0.001	0.001
		Steady State error(e_{ss})	0	0
3.	Sand	Rise Time (t_r)	0.9	0.0001
		Settling Time (t_s)	16	11
		Peak Time (t_p)	6	1
		Max peak Overshoot (M_p)	12.6	1
		Delay Time (t_d)	0.1	0.00001
		Steady State error(e_{ss})	0	0

DOI: 01.IJEPE.4.1.1075